# Agroecology, Agroecosystems and Sustainable Agriculture

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# Agroecology

- **Agroecology employs the principles of ecology to:**
  - **study**
  - **understand**
  - **design**

  **agricultural systems.**

# Agroecology

- **Agroecology has been defined variously as**
  - **the marriage of agriculture and ecology**
  - **the understanding of crop ecology in the context of cultivated systems**
  - **the description of agriculture in ecological terms**
  - **the ecology of food systems**

# Agroecology

- **The application of ecological principles and concepts to the design and management of sustainable agroecosystems**
  1. **Principles and concepts of ecology**
  2. **Design**
  3. **Management**
  4. **Agroecosystems**
  5. **Sustainability**

# Agroecology

- **Agroecology requires multidimensional thinking, the ability to see the whole as well as the context in which functions**
- **There are many obstacles to multidimensional thinking**

# Principles and concepts of ecology

- **The ecosystem:**
  - **A functional system of complementary relations between living organisms and their environment, delimited by arbitrarily chosen boundaries, which in space and time appears to maintain a steady yet dynamic equilibrium (Odum, 1996)**

# Ecosystems

- **Relations in a ecosystem appear to maintain a steady yet dynamic equilibrium**
- **Structural components of an ecosystem**
  - **Biotic factors are the living organisms**
  - **Abiotic factors are environmental:**
    - **Light**
    - **Water**
    - **Temperature**

# Properties of ecosystems

- Diversity of species
- Dominant species
- Abundance
- Vegetational structure (vertical and horizontal)

# Ecosystem organisation

- **Organism** — **individual crop plant**
  - how a single individual performs
  - how the degree of tolerance to stresses determine were it will live
- **population** — **population of crop species or other organisms**
  - determining the factors that control population size and growth
- **community** — **farm field communities**
  - how the interactions of organisms effect the distribution and abundance of the different species
- **ecosystem** — **agroecosystem**
  - web of interaction within its structure

# Structural properties of communities

- **A community is the result of the abiotic factors and of the interactions between its populations**
- **Dominant species due to factors such as:**
  - **relative abundance**
  - **size**
  - **ecological role**

# Structural properties of communities

- **Feeding relations determine the trophic structure and levels as well as the food chain**
  - **producers (autotrophs)**
  - **consumers (heterotrophs):**
    - **herbivors, predators and parasites, parasitoids**
- **Ability to recover after disturbance - stability**

# Ecosystem function

- **A focus on the dynamic processes within the ecosystem.**
  - **Development, conversion and flow of mater and energy**
  - **Interactions and relations between the biotic components and their environment**

# Ecosystem function: energy

- Ecosystems vary in their ability to convert solar energy to biomass
  - Needed by organisms for development
- In ecosystems, energy flows, constantly changing form, and moving from one component to another
- The energy flow in a ecosystem is directly related to its trophic structure

# Energy flow

- Only a small percentage of biomass at one trophic level is converted into biomass at the next trophic level
  - large energy amounts used in maintaining the organisms
  - large amounts of biomass are not used and decomposed
- During decomposition remaining biomass returned to the soil as organic matter
- The total energy output (loss) of an ecosystem is usually balanced by the energy input

# Ecosystem function: energy

- The standing crop or biomass of the plants measures the total amount of energy they have brought into the system
- Gross Primary Productivity (GPP): the total solar energy fixed by photosynthesis
  - The gross primary productivity (GPP) (kcal / m2 , year) measures the rate of the conversion of solar energy to biomass
- Net Primary Productivity (NPP): the energy that remains after subtracting the energy the plants use to maintain themselves from the gross primary

  GPP-energy used by the plant = the biomass of the ecosystem.

# Ecosystem function: nutrients

- Needed for organism growth and development (their life functions)
- Nutrients cycle in ecosystems, constantly changing form and moving from one component to another.

# Ecosystem function: nutrients

- **Nutrients move in complex, interconnected biogeochemical cycles:**
  - **Occur from the local scale (P, S, P, Ca, etc) to the global (C, O, N)**
  - **Involve biotic and abiotic components**
  - **C, N, O, P, and S are the most important**
- **Nutrients have specific routes through agroecosystems depending on:**
  - **type of element**
  - **trophic structure of the ecosystem**

# Ecosystem function: mechanisms of population regulation

- Through a complex combination of biotic interactions and limits set by availability of physical resources, population levels of the various organisms are controlled
- Populations eventually link to and determine the productivity of an ecosystem.

# Ecosystem function: mechanisms of population regulation

- Environmental adaptations
- Predation
- Interference
- Mutualisms
- Competition

# Populations in agroecosystems

- **Populations are dynamic**
  - **In ecosystems occurs the most complex structure biologically possible permitting the establishment and maintenance of dynamic populations of organisms**
- **Population size and the individual organisms that make up them change over time**
- **Species that have the ability to interact with other species as well as with a broad set of tolerances of environmnental conditions are common**
- **Species with narrow set of tolerance and very specialised are common only locally**

# Populations in agroecosystems

- **Interaction with other species may result:**
  - **competition**
    - **Interspecific**
    - **Intraspecific**
  - **mutualism**

# Ecosystem function: dynamic equilibrium

- Ecosystems are in a constant state of dynamic change
- The species richness or diversity of mature ecosystems permits a degree of resistance to all but very damaging perturbations.
- There are cases where periodic disturbance ensure the highest diversity and even highest productivity.

# Dynamic processes in ecosystems

- **Succession: the process of development of an ecosystem, through which appear specific changes in the structure and function of the ecological community over time**
- **Mature ecosystems: maintain a dynamic equilibrium for long time periods**
- **Disturbance: events that change structure and function of an ecosystem**

# State of ecosystems

- Characteristics of change:
  - birth and death of organisms
  - cycling of matter
  - growth and shrink of populations
  - populations shift spatially
- System stability is not a steady state but rather a dynamic and highly fluctuating one
- Ecosystems are stable regarding their:
  - structure
  - functioning
- Stability is due to:
  - complexity
  - diversity

# Characteristics of natural ecosystems

- **Natural ecosystems:**
  - **have components and processes designed through natural selection**
  - **are scaled to renewable resources**
- **Natural ecosystems have proven sustainability and therefore are appropriate models for sustainable agriculture.**

# Principles of agrocology

- Changing one component changes everything else
- Agricultural systems are complex and involve the interaction of many biological and physical factors as well as human ambitions and survival within the natural and built environments
- Agroecology trying to understand agriculture with a multidimensional approach

# The agroecosystem concept

- **Agroecosystems are domesticated ecosystems that are intermediate between natural ecosystems and fabricated ecosystems**

- **An agroecosystem is a site of agricultural production - a farm, for example - understood as an ecosystem**

# The agroecosystem concept

- The boundaries of an agroecosystem are arbitrary
- In practice an agroecosystem is equivalent to an individual farm although it may be a single farm field or a grouping of adjacent farms or fields
- A web of connections spreads out from every agroecosystem into human society and natural ecosystems
- Agroecosystem's spatial boundary is the dividing line between internal and external
- Any substance or energy source from outside the spatial boundaries of the system is an external human input

# The agroecosystem concept

- Agroecosystems are often more difficult to study than natural ecosystems because they are complicated by human management which alter normal ecosystem structures and functions

- The agroecosystem concept provides a framework with which to analyse food production systems as wholes, including their complex sets of inputs and outputs and the interconnections of their component parts.

# Functions in agroecosystems

- **In agroecosystems the functions determine the success or the failure of a particular crop or management practice**

# Agroecosystem resources

(adapted from Norman 1979)

- **Natural**
  - Soil, water, climate, natural flora and fauna
  - Topography
- **Human**
  - People who leave and work in the farm
- **Capital**
  - Good and services created, purchased or borrowed by the people associated with a farm
- **Production**
  - Agricultural output of the farm

# Ecological processes in agroecosystems

- **Energetic**
  - **Energy flows in the production process**
    - **Solar energy, human labour, mechanised energy inputs, energy content of introduced inputs**
    - **Human energy shapes the structure of an agroecosystem**

# Ecological processes in agroecosystems

- **Biogeochemical**
  - **Nutrients flow through biochemical processes**
  - **Optimisation of biogeochemical processes requires the development of optimal soil structure and fertility:**
    - **Regular input of organic residues and organic mater**
    - **Sufficient level of microbial activity to decay organic materials**
    - **Conditions that ensure continual activity of soil stabilising agents like earthworms**
    - **A soil protective covering of vegetation**

# Ecological processes in agroecosystems

- **Hydrological**
  - **Water is a fundamental component :**
    - **having its physiological role**
    - **Effecting inputs of nutrients to the agroecosystem and losses though leaching and erosion**
  - **The water balance of an agroecosystem is effected by the agricultural practices**
  - **Rainfall is the main determinant of the crops adopted in the local conditions**

# Ecological processes in agroecosystems

- **Successional**
  - **Succession is radically changed with conventional agriculture**
    - **Existing communities are disturbed**
    - **Maintenance of a single man made community**
  - **The tendency for complexity is detained by using agrochemical inputs**
  - **Succession and complexity may partly re-established by:**
    - **Enhanced crop biodiversity**
      - **Minimising external inputs**
    - **Polycultures**

# Ecological processes in agroecosystems

- **Biotic regulation**
  - **Control of succession and of insect pest and diseases determines production continuity in agroecosystems**
  - **Ecological management of organisms in agroecosystems employs a combination of three strategies:**
    - **No action**
    - **Preventive actions**
      - **Resistant varieties, manipulation of planting dates, row spacing etc.**
    - **Successive actions**
      - **Chemical pesticides, biological control, cultural techniques etc.**

# Natural ecosystems and agroecosystems compared

- Agroecosystems differ from natural ecosystems regarding
  - Energy flow - open systems
  - Nutrient cycling - minimum
  - Population regulating mechanisms
  - Stability
- Agroecosystems are open systems receiving inputs from the outside and producing outputs that enter external systems
- Actual systems of agroecosystems and ecosystems exist on a continuum

# Natural ecosystems and agroecosystems compared

**Agroecosystems differ from natural ecosystems regarding**

- **the auxiliary energy source that enhance productivity is processed fuels (along with human and animal labour)**
- **diversity is greatly reduced by human**
- **dominant plants and animals are under artificial rather than natural selection**
- **the control is external and goal oriented**

# Natural ecosystems and agroecosystems compared

**Agroecosystems differ from natural ecosystems regarding**

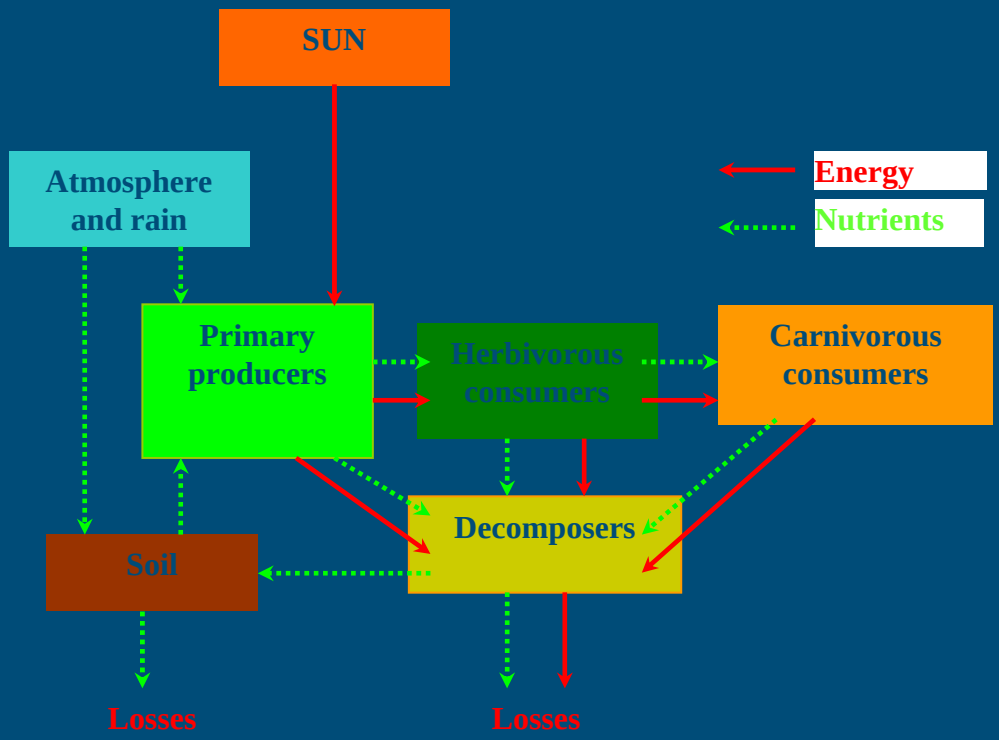
- **large input and output environments**
- **extensive dependence on and impact on externals - like the cities**
- **the power density of industrialised agriculture is about ten times greater than that of most ecosystems and approaches in severity that of urban-industrial areas:**
  - **through agricultural chemical pollutants**
  - **through soil erosion on waterways**
  - **through pollutants on the atmosphere**
  - **through effects on other global life support systems**

# Designing agroecosystems

- **Agroecosystems can be designed in order to come close to resembling natural ecosystems in terms of such characteristics such as:**
  - **species diversity**
  - **nutrient cycling**
  - **habitat heterogenity**
- **Designing sustainable agroecosystems means achieving natural ecosystem-like characteristics while maintaining a harvest output**

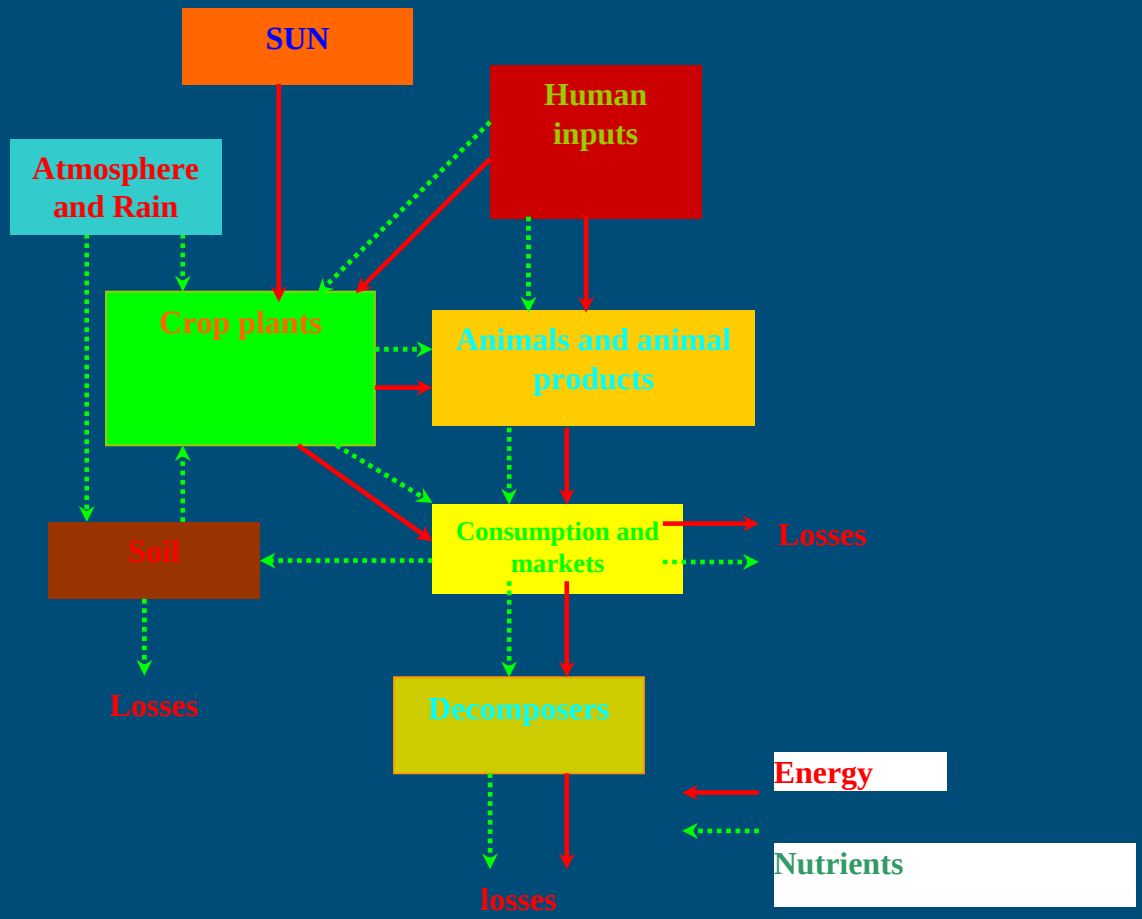
# Functional components of an ecosystem

(adopted by Gliessman, 2002)



# Functional components of an agroecosystem

(adopted by Gliessman, 2002)



# Differences between ecosystems and agroecosystems

- **More open energy flow:**
  - **More inputs (fuel, organic matter).**
  - **More outputs (harvest).**
- **More open nutrient cycles.**
- **Reduction of capacity for self-regulation:**
  - **Less diversity**
  - **Simplification of structure and trophic levels**
  - **Control of population of organisms**

# Comparison of Natural and Managed agroecosystems

- **A comparison:**
  - **Demonstrate / articulate differences**
  - **Identifies commonalities useful for new designs and management alternatives to agriculture**

# Comparison of Natural and Managed agroecosystems

- **Sustainable long run natural ecosystems:**
  - **Exhibit greater gross production than managed agroecosystems.**
  - **Have smaller net yields of target products because more of their production is re-invested to design and maintain diverse structure and co-operative pathways.**
  - **This promotes important properties for sustainable production including aspects of:**
    - **Autonomy.**
    - **Self sufficiency.**
    - **Homeostasis,**
    - **Nutrient retention.**
    - **Resilience.**

# Comparison of Natural and Managed agroecosystems

- **Ecosystems:**
  - **Never direct resources to single products.**
  - **Generate nested designs which support multiple services.**
  - **Services are integral to agroecosystem function.**
  - **Many of the services are delivered for human purposes with minimal or no investments from the economy.**

# Comparison of Natural and Managed agroecosystems

- **Most of the managed gross production is transformed into extractable biomass producing greater yields per unit time through subsidies in the form of:**
  - **Fossil fuels.**
  - **Irrigation.**
  - **Pest management products.**
  - **Fertilisation products.**
  - **Direct planting.**
  - **Genetic engineering.**

# Comparison of Natural and Managed agroecosystems

- After accounting all subsidies and investments little “net” contribution is delivered.

# Comparison of Natural and Managed agroecosystems

- **Agroecosystem integrity is compromised by:**
  - **Reducing local biodiversity,**
  - **Disorganising nested functions,**
  - **And indirect environmental loads.**
- **The renewal capacity of agroecosystems is diminished and requires increasing engineering solutions and expensive remedies that draw resources away from other sectors.**

# Comparison of Natural and Managed agroecosystems

- Efficiency is greater in natural ecosystems
- Turnover times and rates of delivery are slower and scaled to periodicity of local renewable resources

# Comparison of Natural and Managed agroecosystems

- **In agricultural production:**
  - **ecosystems services and ecosystem health are not recognized as necessary or contributory**
  - **attention is not paid to constraints or indirect effects**

**due to narrow focus on crop yield.**

# Comparison of Natural and Managed agroecosystems

- **In agroecosystem management net benefits may be greater than single product revenue alone if:**
  - **Agriculture is recognised as stewardship.**
  - **Agroecosystem health is promoted.**
  - **Non-market ecological services are considered.**

# Comparison of Natural and Managed agroecosystems

- **Designing and managing agriculture with mimicking structure and function of local ecosystems promotes sustainable production scaled to local conditions.**

# Important structural and functional differences between natural ecosystems and agroecosystems

| | Natural | Agroecosystem | | |
|---|---|---|---|---|
| | ecosystem | *Traditional* | *Conventional* | *Sustainable* |
| Productivity | Medium | medium | low/medium | med/high |
| Species diversity | high | med. /high | low | medium |
| Structural diversity | high | med. /high | low | medium |
| Functional diversity | high | med. /high | low | med. / high |
| Output stability | medium | high | low/med. | high |
| Biomass Accumulation | high | high | low | med./high |
| Nutrient recycling | high | high | low | high |
| Trophic relationships | high | high | low | high |
| Natural population regulation | high | high | low | med./high |
| Resistance | high | high | low | medium |
| Resilience | high | high | low | medium |
| Dependence on external human inputs | low | low | high | medium |
| Autonomy | high | high | low | high |
| Human displacement of ecological process | low | low | high | low/medium |
| Sustainability | high | med./high | low | high |

# Characteristics of Sustainable Systems

- **Meaningful for sustainability are the following ecosystem properties and general characteristics:**
  - **They are fit to available, flow-limited renewable energy.**
  - **Living systems organise cyclically responding to:**
    - **External resource oscillations.**
    - **Internal design constrains.**
  - **Pulsing systems appear to be more resilient and may maximize power.**
  - **There is recycling of minerals and nutrients.**
  - **Processes and components are organised and optimised.**

# Characteristics of Sustainable Systems

- They are resilient.
- Feedbacks are integral to performance.
- Mutual and symbiotic relations (interrelations of co-operation) are developed.
- There is connectivity within and between systems.
- Components and processes are nested.

# Characteristics of Sustainable Systems

- Hierarchies of energy transformations are developed.
- They are self designed according to biophysical limitations.
- There is not exploitation of investment.
- Gross production is allocated to networks and not to single products.
- Net production is used for storage and exchange.

# Characteristics of Sustainable Systems

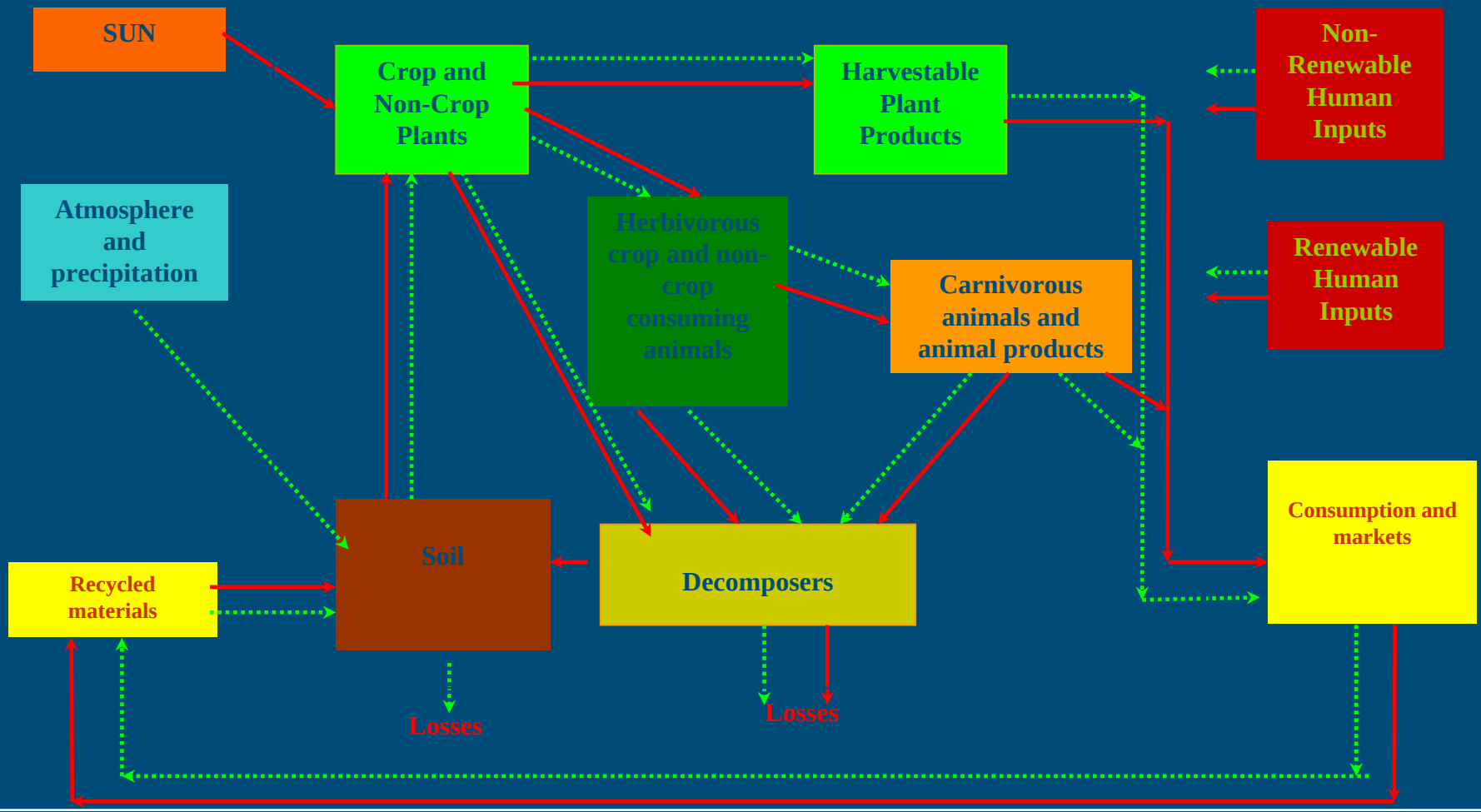
- As systems become larger and / or more complex more of available energy is required for maintenance.
- Mutualism increases as resources become limiting.
- Available and useful power is maximised through designs that tend to be open, self organising systems.

# A general principle

- **The greater the structural and functional similarity of an agroecosystem to the natural ecosystems in its biogeographic region, the greater the likelihood that the agroecosystem will be sustainable.**

# Functional components of an ecosystem converted to a sustainable agroecosystem

(adopted by Gliessman, 2002)



# Sustainable agroecosystems

- **Sustainable agroecosystems**
  - **may focus on export of harvest to distance markets**
  - **they need to purchase a significant part of their nutrients externally**
  - **There is a strong impact of market systems on agroecosystem diversity and management.**
  - **May have lower or more variable than conventional ones due to year to year weather variation**
    - **Such yield variations are more than offset through the advantages gained by**
      - **reducing dependence on external inputs**
      - **Relying on natural controls of pests**
      - **Reducing negative off-farm effects of farming activities**